AN

ARTIFICIAL EYE,

WITH SOME

Practical suggestions as to its use,

BY

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CONTENTS.

III. Hypermetropia.

(*a.*) Retinal Images of distant objects.

„ „ of near objects.

(*b.*) Ophthalmoscopic Examination.

(*i.*) Direct method.

(*ii.*) Mirror alone at a distance.

(*iii*) Indirect method.

IV. Astigmatism.

Definition.

Refraction at an Astigmatic surface.

(*a.*) Retinal Images in an Astigmatic Eye.

Varieties of Astigmatism.

(*b.*) Ophthalmoscopic Examination.

(*i.*) Direct method.

(*ii.*) Mirror alone at a distance.

(*iii.*) Indirect method.

V. Retinoscopy or Shadow-Test.

Appearances seen.

Explanation.

Application to Astigmatism.

INTRODUCTORY.

An Artificial Eye is useful for several purposes, the chief of which are—practice in the use of the Ophthalmoscope, and the working out of problems connected with the refraction of the eye.

The instrument to which this pamphlet refers can lay claim to no originality in its conception, and is extremely simple in its construction,—so simple that anyone possessed of ordinary ingenuity could reproduce its essential features.

My wish is to endeavour, in the following remarks, to imitate the simplicity of the instrument, so that I may make clear to my readers the rationale of the various methods of using the ophthalmoscope, and of estimating refraction, without assuming that they possess more than the most elementary knowledge of optical principles.

Having often experienced the want of an efficient and cheap artificial eye, I constructed one for myself very like the instrument to be presently described, out of the eye-piece of a microscope. I found this useful in such a variety of ways that it occurred to me, that it might be equally so to others, and acting on my suggestions Messrs. Pickard & Curry have produced the instrument to which this pamphlet refers.

Before describing its construction and use, it will be well briefly to consider the optical properties of the natural eye.

The natural eye is a nearly spherical chamber; the anterior fifth of its wall, the cornea, is transparent, while the remainder, the sclerotic, is opaque, and, is lined by an expansion of the optic nerve—the retina. The length of the globe from the centre of the cornea to the central point at the posterior pole is 22·2 millimetres. It contains two fluids, the aqueous and vitreous,—which for optical purposes, may be considered as one, since they possess the same refractive power. Suspended in the fluid is the bi-convex crystalline lens which has a higher refractive power.

Rays entering the eye undergo refraction (1) at the anterior surface of the cornea, (2) at the anterior surface of the lens, (3) at its posterior surface, and the effect of each is to render the rays more convergent. In the normal eye parallel rays are focussed in a point on the retina; in other words, the retina lies at the principal focus of the dioptric system of the eye.

By the action of the ciliary muscle the convexity of the lens, and therefore its refractive power, can be increased: this action is called accommodation, because by it the eye is *accommodated* for a near point: in front of the lens is the iris which forms a diaphragm, whose size can be varied.

In speaking of the refraction of an eye, the accommodation is always assumed to be relaxed.

An eye may depart from the normal standard in two directions, the retina may lie beyond the principal focus—Myopia, or in front of it—Hypermetropia. The mean condition, when it lies at the principal focus, is called *Emmetropia*; while all departures from this condition, are classed under the general term *Ametropia.*

In diagrams and calculations it is usual to represent the three refractions, which the rays undergo, by a single equivalent change in direction taking place at the first surface. The reduced eye of Donders, constructed on this principle, is very convenient, as in it the relation of retinal images to external objects is almost the same as in the natural emmetropic eye (as 1 to 1·1), while the dimensions used are such as render calculations easy. It is supposed to represent a single chamber filled with fluid, whose refractive power is to that of air as 4 : 3. It is closed in front by a cornea having a radius of curvature of 5 m.m., and its length is 20 m.m.

In the Artificial Eye the refracting surfaces are replaced by a convex lens having a focus of 40 millimetres. The length of the eye can be varied from 30 to 65 m.m. so that the retina can be placed at, beyond, or in front of the principal focus, while its position at any moment is indicated by a pointer on a scale. Immediately in front of the lens is a disc containing diaphragms of different sizes to represent the iris, and in front of this again are two clips, A and B, placed respectively at 5 and 10 m.m. from the lens, these are intended to hold lenses by which an error of refraction can be increased or

neutralized. A third clip, C, travels along a graduated bar, and is intended to hold a lens, a ground glass screen, or any object whose image it is wished to form on the retina. The bar can itself be shortened, lengthened, or removed altogether. See fig. 1.

FIG. 1.

As regards the fundus itself no attempt has been made to illustrate morbid conditions, as these can be learnt better from plates and living specimens but I have been content with (1) a representation of the normal fundus, and (2) a ground glass on which are drawn a circle 4 m.m. in diameter, and two lines at right angles to each other graduated in millimetres; these will be found useful in studying the size of retinal images and the amount of the fundus visible under certain conditions.

The clips are made so that the lenses of the trial cases in general use will fit them, but, for the convenience of those who do not possess such a case, + 10 D., + 8 D., and — 8 D. spherical, and + 5 D. cylindrical lenses are supplied, in addition to a ground glass, and a screen with radiating lines as a test object in astigmatism.

The scales have been graduated in centimetres and millimetres, because the metrical system is more convenient for small measurements and for calculations.

Before describing a few experiments which may advantageously be made with the Artificial Eye, it will be well to explain the relation between the metrical system of linear measurement and numbering of lenses, and that which was formerly more generally used in this country, as well as a few other points in relation to lenses. A Metre (M) is equivalent to 39½ English inches and is divided into a hundred Centimetres (c.m.), while each centimetre is subdivided into 10 Millimetres (m.m.). The relation therefore of inches to centimetres is for all practical purposes, as 5 : 2—accurately as 5 : 1·975.

Lenses were formerly numbered according to their focal length in inches: the effect of this was that the higher the number of the lens, the weaker was its refractive power. To obviate this it was necessary in making calculations to convert the whole number into a fraction by inverting it, thus instead of speaking of a 2 in. and a 6 in. lens we spoke of $\frac{1}{2}$ and $\frac{1}{6}$. The addition and subtraction of fractions however was troublesome, and the intervals between the higher powers were necessarily irregular. These drawbacks are avoided by using the Metrical system: in this, the unit is a glass of a Metre focal length; this is called a Dioptre (written 1.D.), and all other lenses are multiples or fractions of this and are numbered accordingly: thus a lens of twice this strength is 2.D. and would have a focal length of half a metre, the focal length of 3.D. would be a third of a metre, and so on, while those weaker than 1.D. are expressed as decimal fractions, thus 0·50.D. would have a focal length of two metres. The focal length in centimetres therefore of any lens numbered on this plan is found by dividing 100 by the number of Dioptres represented by the lens, while the focal length in inches is found by dividing 39·5 by the same number.

Convex lenses usually have the sign + placed before them, concave lenses must be preceded by the — sign.

Lenses are spherical or cylindrical. In Spherical lenses one or both surfaces are portions of the surface of a sphere: hence every meridian of the lens has the same curvature, and the same refractive power; rays therefore coming from a point, being refracted by such a lens, will be brought to a focus at a point.

In Cylindrical lenses both surfaces may be portions of the surface of a *cylinder* (usually one surface is plane.) If a circle be described on the outside of a hollow glass cylinder, the enclosed portion would represent the surface of a convex cylindrical lens; the meridian corresponding to the *axis* of the cylinder would be plane, while the meridian at right angles to this would have the greatest convexity, and the other meridians an intermediate curvature.

If, now, a similar circle be described on the inner surface, the included portion will represent the surface of a concave cylindrical lens; as in the preceding instance the axis of the cylinder is the non-refracting meridian. In a cylindrical lens the axis is always marked by a line, and the lens is numbered according to refraction of the meridian of greatest curvature, *i.e.* the meridian at right angles to the axis. It is evident, since such a lens does not refract equally in all its meridians, that rays coming from a point and being refracted by it cannot be focussed in a *point*, a refracting surface of this nature is therefore said to be astigmatic (*a.* privative, and *stigma* a point.)

If the reader will now make the following experiments with the artificial eye, he will gain a practical insight into the details of refraction and its errors, and will learn how to overcome the difficulties which arise in commencing the use of the ophthalmoscope.

I. EMMETROPIA.

Adjust the eye so that the index points to 40—the retina now lies at the principal focus of the dioptric system (represented by the lens), and the eye is therefore in the condition of Emmetropia.

(*a.*) **Formation of Retinal Images.** *Affix the glass retina.*—If the eye is now turned towards the window, it will be seen that well defined images of distant objects are formed on the retina; and if the images are measured, as they can be by the markings on the retina, it will be found that they bear the same proportion to the objects they represent as exists between the respective distances of the image and the object from the lens; or

$$\frac{\text{Size of image.}}{\text{Size of object.}} = \frac{\text{Distance of image.}}{\text{Distance of object.}}$$

Since parallel[1] rays are focussed in a point on the retina, it follows that rays from any point on the retina must emerge from the eye parallel, this fact will presently be seen to have an important bearing.

If the eye be now directed to a near object, the latter forms a very blurred and indistinct image on the retina. The natural eye, as we have seen, "accommodates" itself for near objects by increasing the convexity of the crystalline lens: in the artificial eye we can increase the refraction by placing a convex lens in front of it. The strength of the lens which will be required will depend on the distance for which it is desired to accommodate. Thus if a card be placed in clip C at a distance of 10·5 c.m. from the eye, a lens placed in clip A will be 10 c.m. from the card, and if its focus is 10 c.m. it will render the diverging rays parallel, and they will then be focussed on the retina; + 10.D. is such a lens.

(*b*) **Ophthalmoscopic Examination.** (*i.*) Remove the bar which carries C, and place the eye with the glass retina towards the window; now, holding the head as near as possible, look into the eye, and the markings on the retina are clearly seen. This is because the rays coming from any point on the glass retina are parallel, and can therefore be focussed on the observer's retina, if his own eye is emmetropic. At first there is some little difficulty in seeing the markings clearly, owing to the observer unconsciously using his accommodation; but if the eye be shortened a little, and then gradually extended to 40 m.m., it will, after a few trials, be found easy to relax the accommodation completely.

Affix the painted retina. It will now be found that no view can be obtained of the interior of the eye, because the observer's head prevents the light from entering. This difficulty is overcome by using the ophthalmoscope, which is essentially a mirror the centre of which is transparent, so as to

1 *Note*—Rays coming from a point distant not less than 16ft. may be considered to be parallel.

allow of some of the rays returning from the eye to pass through, and reach the observer's eye placed behind it. Place a lamp on one side of, and on the same horizontal level as, the artificial eye, but a little further back—then reflect the light into the eye from the mirror, held as close to it as possible. The details of the retina will then be clearly seen. This is called the *direct method* of using the ophthalmoscope; the details of the fundus are seen magnified and in their true position: the *image* is therefore *erect.*

(*ii*) If the head be now gradually withdrawn it will be found that less and less of the fundus is seen, and that at a distance of several feet only a minute fraction of a millimetre is visible; as the image continues however to occupy the whole pupil, the portion seen is of course proportionately magnified. This gradual diminution of the area seen is due to the fact that the rays from any point on the retina emerge parallel to the axis on which that point is situated; since the pencils of parallel rays from any two such points diverge from each other both cannot reach the observer's eye.

If in this experiment the glass retina is used, the actual size of the area seen at different distances can be measured.

(*iii.*) *Replace the glass retina.* Place the lens + 10 D in A; we have seen that the effect of this is that the image of an object placed in C, 10·5 c.m. from the eye, is formed on the retina. The converse must also be true that an image of the retina will be formed at C. If the ground glass screen be placed in C, 10·5 c.m. from the eye, and the latter placed with the retina towards a good light, an inverted image of the markings on the retina will be formed on the ground glass.

If the ground glass screen be now removed the image is still formed in the same position in the air, and can be there seen, if the observer's head is in line with the principal meridian of the eye. Observe that as the head is moved from side to side the image appears to move in the opposite direction.

Replace the painted retina leaving the lens *in situ*: place the light as before, and, holding the mirror at the distance of about two feet, throw the light into the eye: an *inverted image* of the retina is now seen—this is called the *indirect method* of using the ophthalmoscope.

This indirect method should now be practised, the lens being held in one hand and the mirror in the other.

If the lens be withdrawn a little from the eye, it will be seen that the image remains of the same size.

II. MYOPIA.

Lengthen the eye to more than 40 m.m., thus rendering it Myopic. The retina now lies beyond the principal focus of the eye, parallel rays will therefore come to a focus before reaching the retina, and the only rays which can be focussed on the retina are *diverging* rays. Conversely, rays from any point on the retina are *convergent* on leaving the eye. (See Fig. 2.)

Fig. 2.

(*a*) **Formation of Retinal Images.** *Affix the glass retina.*—Distant objects will only form blurred images on the retina, but if an object be gradually brought nearer, a point will be found at which it will form a clear retinal image. This is the farthest point of distinct vision for our myopic (or shortsighted) eye; and is often expressed by the symbol, *p.r.* (*punctum remotum*.)

(*b*) **Ophthalmoscopic Examination.** (*i.*) On examining by the direct method, the markings on the fundus will be seen indistinctly, or not at all, because the emmetropic eye cannot focus converging rays. If a concave lens, which renders the rays parallel, be placed behind the ophthalmoscope, the details will be clearly seen. A stronger concave lens will render the rays divergent, and they can then only be focussed by the observer with the aid of his accommodation. The *weakest* concave lens therefore with which the retina can be clearly seen is said to *correct* the myopia, for it renders the converging rays from the retina parallel, and, conversely, would cause parallel rays to be focussed on the retina. If, now, a lens of the same strength as that used in the ophthalmoscope be placed in front of the eye, distant objects will be seen to form clear images on the retina as in emmetropia.

(*ii.*) If, using the mirror alone, the head be withdrawn, it will be found that at a certain distance an inverted image of a considerable area of the fundus is seen (*a' b'* Fig. 2.) This is a *real* image and is formed in the same way as the inverted image produced by the convex lens in emmetropia, only that the rays are in this case already convergent, and therefore no lens is needed.

We saw above that at the "far-point"—whose position varies with the amount of myopia—an object formed an inverted image on the retina: in the same way an inverted image of the retina is formed at the "far-point"; the latter statement can be proved by the following experiment.—Ascertain the "far-point" of the eye experimentally as in *a*, then place the ground glass screen in C, at the "far-point"—if a good light be placed behind the glass retina a distinct image of the latter is formed on the glass screen.

The "far-point" of the myopic eye can also be found by the following formula:—(F being the principal focal distance of the dioptric system = 40 m.m. f the distance of retina from the lens. pr, the "far-point"), viz:—

$$\frac{1}{pr} = \frac{1}{F} - \frac{1}{f}$$

So that if the eye were lengthened to 50 m m., the "far-point" would be at 200 m.m.

In order that a lens should correct the myopia, it is necessary that its principal focus should coincide with the "far-point," for it will then render parallel rays as divergent as they would be if they came from that point.

For Example:—In the above instance, the correcting lens, if placed in clip A, would require to have a focal length of 195 m.m. (5·12 D.)

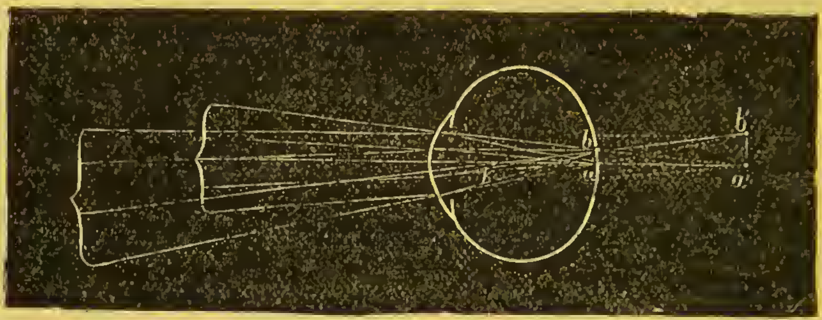
(iii.) The indirect method of using the ophthalmoscope can be employed as in emmetropia, when the lens will render the converging rays still more convergent. It will be found that as the lens is withdrawn from the eye the image *increases* in size.

III. HYPERMETROPIA.

Shorten the eye to less than 40 m.m. The retina now lies in front of the principal focus, and the eye is therefore Hypermetropic.

Parallel rays would now come to a focus beyond the retina, and only *convergent* rays could be focussed on it: hence rays from any point on the retina would be *divergent* on leaving the eye. (See Fig. 3.)

Fig. 3.



(*a*) **Formation of Retinal Images.** Since there are no convergent rays in nature, no clear images can be formed on the retina; the images of near objects will however be more blurred than those of distant ones.

(*b*) **Ophthalmoscopic Examination.** *Replace the painted retina.* (*i.*) On examining by the direct method it will be found that the details are still clearly seen, because the emmetropic eye can focus diverging rays by the aid of its accommodation. If now a convex lens be placed behind the ophthalmoscope the retina will still be visible, whereas in Emmetropia the weakest convex lens will be found to blurr the image. The lens which renders the emergent rays parallel is said to *correct* the Hypermetropia, for since the rays from the retina are rendered parallel, parallel rays would be focussed on the retina. The *strongest* convex lens with which the fundus can be clearly seen is therefore the measure of the Hypermetropia.

(*ii*) If, using the mirror alone, the observer now withdraws his head, he will see an erect image (*a'b'* Fig. 3) of a considerable portion of the fundus (*a b*). We saw that in Emmetropia the pencils of rays from any two points diverged from each other so that both could not reach the observer's eye—now, however, the pencils of rays from the points *a* and *b* (fig. 3), although diverging from each other, are constantly increasing in size, owing to the divergence of their component rays, hence the eye receives rays from both pencils. As the rays reach the observer's eye in a state of divergence, they appear to come from the point where they would meet if prolonged: therefore images of *a* and *b* are seen at

a' and *b'*, (and therefore an image of the portion of retina between them.) This is a *virtual* image, *i.e.* it is not formed by a meeting of the actual rays, but of their imaginary prolongations. If the observer moves his head from side to side he will find that the image appears to move in the same direction as his head.

In Myopia we saw that in order that rays may be focussed on the retina they must *diverge* as if coming from the "far-point." In Hypermetropia the rays must *converge* to such an extent that they would meet, if prolonged, *behind* the eye: the "far-point" is therefore said to be *negative*, and is distinguished by the minus sign. In Emmetropia the "far-point" is at infinite distance.

The "far-point" in Hypermetropia can be found by the formula—

$$\frac{1}{pr} = \frac{1}{f} - \frac{1}{F}$$

In order that a lens may correct Hypermetropia, it is necessary that its principal focus should coincide with the far-point, for it will then give to parallel rays such a degree of convergence that they would meet there if prolonged.

For Example—The length of the eye being 37 m.m., *pr.*=493 m.m., the correcting lens placed in A, must therefore have a focal length of 498 (+ 2 D.)

(*iii*) If the inverted method of using the ophthalmoscope be now employed, it will be found that the image *diminishes* in size as the lens is withdrawn.

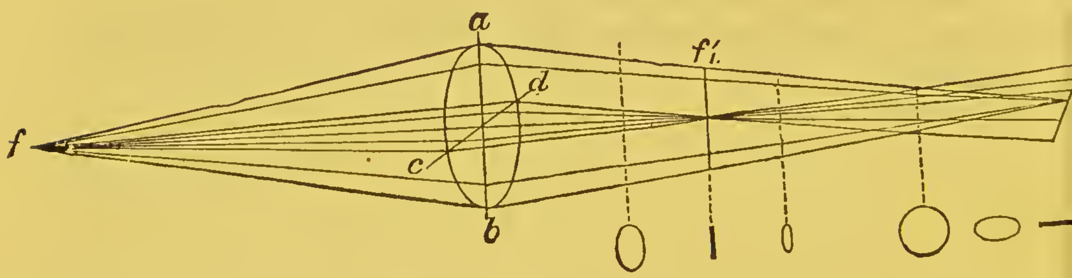
IV. ASTIGMATISM.

This is the state of refraction in which the eye does not refract equally in all meridians: the fault usually consists in the vertical meridian of the cornea having a shorter radius of curvature, and therefore a greater refractive power, than the horizontal. The meridians which differ most from each other, *i e.* that having the greatest and that having the least refraction, are at right angles to one another, and are called the *principal meridians.*

We have seen that a cylindrical lens has one of its meridians plane, while the one at right angles to this has the greatest curvature: it is evident therefore that such a lens placed in front of a non-astigmatic eye would render it astigmatic, and that by one of suitable strength the difference between the principal meridians of an astigmatic eye would be neutralized, and the astigmatism therefore *corrected.*

The effect of an astigmatic surface upon the course of rays falling on it will be made plainer by the accompanying diagram. Let *a c b d* (Fig. 4) be an astigmatic surface, circular in shape but viewed obliquely. Let a pencil

Fig. 4.



of rays from a point *f* fall on this, and let the focus for rays which pass through the horizontal meridian, *c d*, be at f_1' and that for those which pass through the vertical meridian, *a b*, be at f_2'. The outline of the section of the cone of rays between *a c b d* and f_2' will vary with the position of the section. Thus between *a c b d* and f_1' it will be an oval, of which both the vertical and horizontal meridians will diminish as f_1' is approached, but the horizontal meridian will diminish more rapidly than the vertical, so that the vertical diameter gradually increases in proportion to the horizontal until at f_1' (the focus of the horizontal meridian) the section will be indistinguishable from a vertical line. Between f_1' and f_2' the vertical meridian will continue to diminish, while the horizontal will increase, so that we get successively an oval with a long vertical diameter, a circle, an oval with a long transverse diameter, and finally

at f_2' (the focus of the vertical meridian), a horizontal line. Hence we get this rule :—

Rays from a point, being refracted at an astigmatic surface, are not focussed in a point: but, at the focus of each of the principal meridians, a linear image of the point is formed, and the direction of this is at right angles to the meridian at whose focus it is formed.

(*a.*) **Formation of Retinal Images.** The following experiment will impress the above rule on the memory, and serve to explain some of the phenomena connected with the vision of an astigmatic eye.

Let the reader render his own eye astigmatic by placing a cylindrical lens before it, then let him look at a point of light, obtained by making a pin-hole aperture in a card and holding it in front of a lamp. The eye being accommodated for the point of light, the retina will be at the focus of the unaltered meridian, *i.e.* the meridian corresponding to the axis of the cylinder: therefore on the retina a linear image of the point of light is formed, and its direction is at right angles to the emmetropic meridian. The point of light will therefore be seen as a line at right angles to the axis of the cylinder.

Now carry the experiment a step further by looking at a line, or, better still, at two parallel lines separated by only a narrow space. It will now be found the lines are only clearly seen when their direction is at right angles to the emmetropic meridian. This is because a linear image of every point on the line is formed on the retina; when the direction of these linear images is the same as that of the line, they all overlap one another in the same direction, and so form a line by their super-position; but, when the direction of the linear images is at right angles to that of the line, the latter is widened out and blurred, while the space between the lines is obliterated. Hence we get this rule :—

An eye with simple astigmatism (one of the principal meridians emmetropic) only sees clearly lines which are at right angles to its emmetropic meridian.

The amount of astigmatism is expressed by the difference in the refraction of the two principal meridians, as indicated by the lens which corrects that difference. As regular astigmatism is a difference between the refraction of the two principal meridians, it is evident that strictly speaking, there can be only one *kind* of astigmatism, unless differences in the direction of the principal meridians be taken into account, but a classification based on the refraction of the eye after the astigmatism is corrected is useful;—such a classification is shewn in the following table, together with the way of producing each kind of stigmatism in the artificial eye.

Refraction of Principal Meridians.		Name.	Length of Artific Eye necessary w +5 *cyl* in clip A
Myopic	Myopic	Compound Myopic Ast^m.	65 to 40
Emmetropic	Myopic	Simple Myopic Ast^m.	40
Hypermetropic	Myopic	Mixed Ast^m.	40 to 33·1
Hypermetropic	Emmetropic	Simple Hypermetropic Ast^m.	33·19
Hypermetropic	Hypermetropic	Compound Hypermetropic Ast^m.	33 19 to 3

The experiments which were made with the Emmetropic, Myopic, and Hypermetropic eye, should now be repeated with the eye rendered Astigmatic by means of a cylindrical lens.

In Simple Astigmatism it will be found that the only lines which form sharply defined images on the retina are those which are at right angles to the emmetropic meridian.

(*b*) *i.* **Ophthalmoscopic Examination.** In direct ophthalmoscopic examination, the observer's retina is at the focus of the rays which pass through the emmetropic meridian, so that by the rule given on page 17, only those lines form clear retinal images whose direction is at right angles to that meridian.

(*ii.*) With the mirror alone held at a distance, an image (inverted in Myopia, erect in Hypermetropia,) will be seen of the vessels or lines which run at right angles to the *ametropic* meridian, for the image is formed at the "far-point" of the ametropic meridian.

For Example—If the vertical meridian were Myopic, and the horizontal Emmetropic (Simple Myopic Astigmatism), an inverted image of the horizontal vessels or lines would be seen, but none of the vertical vessels.—If the vertical meridian were Emmetropic, and the horizontal Hypermetropic (Simple Hypermetropic Astigmatism), an erect image of the vertical vessels would be seen, but none of the horizontal.—While, if the vertical meridian were Myopic, and the horizontal Hypermetropic (Mixed Astigmatism), an inverted image of the horizontal, and an erect image of the vertical vessels or lines would be seen.

The case of Simple Myopic Astigmatism can be demonstrated with the glass retina, and the ground glass in C placed at the "far-point" of the myopic meridian.

(*iii.*) In using the *indirect method*, the disc will change its shape as the lens is withdrawn, for it *diminishes* in the *hypermetropic* and *enlarges* in the *myopic* meridian.

V. RETINOSCOPY OR SHADOW-TEST

There is a series of experiments which I have left till the last because the results will be better appreciated if the characteristic features of the several kinds of ametropia are thoroughly understood; I refer to the employment of a test for refraction which has been called Keratoscopy and Retinoscopy, but would be more appropriately named the " Shadow-test."

Affix the painted retina.—Render the eye Hypermetropic by shortening it to about 35 m.m., and hold the mirror at a distance of 4ft. so that the pupil appears occupied by a red reflex. Now rotate the mirror slightly from side to side on its vertical axis, and a shadow will be seen to move a certain distance across the pupil from each side alternately, always coming from the side towards which the mirror is rotated, and therefore moving in the *opposite* direction to the mirror. The shadow is bounded by a distinct vertical edge, which separates it from the bright portion of the pupil; if the mirror be rotated on any other axis the direction of the edge of the shadow will also change, and will still be parallel to the axis of rotation, the direction of its movement being at right angles to the edge. Now, while the mirror is held and rotated as before, let the eye be gradually lengthened, the shadow will be seen to make a greater movement with the same rotation of the mirror, its edge to become less defined, and the illumination of the bright portion to grow less, so that, as the eye is lengthened. it becomes more and more difficult to define the shadow, and, for a short time, it is impossible to see any distinct shadow; but, as the lengthening of the eye continues, it re-appears, but now moves in the *same* direction as the mirror, and it will be found that the eye has been rendered *myopic.*

The explanation of these appearances is as follows—

The mirror being concave, an image of the flame is formed in the air near its principal focus. If the eye under examination is slightly myopic, so that its " far-point" coincides with the aërial image, the latter will be reproduced on the retina. In every other state of refraction the retinal image will be a circular patch of light,—a diffusion-image—whose size is proportionate to that of the pupil, and to the extent to which the refraction of the eye differs from the slight degree of myopia just indicated; the diffusion-image however enlarges more rapidly with increasing degrees of myopia than with increasing degrees of hypermetropia.

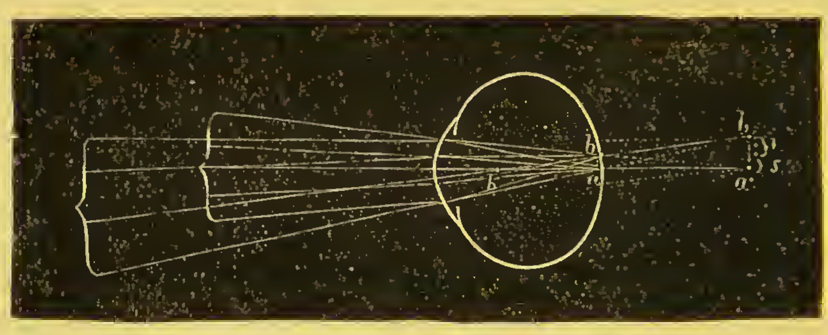
The above facts can be easily verified experimentally by means of the glass retina.

If the latter be viewed from behind, the diffusion-image will be seen to move in the opposite direction to that in which the mirror is rotated in every state of refraction; (part of the image becomes cut off on the side towards which it

moves, but this does not affect the explanation). It is evident therefore that the difference in the apparent movement of the shadow in myopia and hypermetropia does not depend on a real difference in the movement of the light on the retina, but on the fact that in myopia the fundus is seen *inverted.* It is therefore essential that the observer should be beyond the "far-point" of the myopic eye.

To explain the nature of the so-called "shadow" we will assume that the eye is hypermetropic, and that, in the first position of the mirror, the diffusion-image exactly coincides with the portion of the fundus (*a b* Fig. 5) which is visible; in this case the whole of the image *a′ b′* will be illuminated, and the whole area of the pupil will give a bright reflex.

Fig. 5.



Now let the mirror be rotated in any direction, say downwards, the diffusion-image will now shift a little upwards, leaving the portion of *a b* nearest to *a* unilluminated, in the same way the lowest part of *a′ b′* (s), and therefore of the area of the pupil, will be in shade, so that, as the mirror has been rotated downwards, the 'shadow' has moved upwards.

In the same way in myopia, if we assume that in the first position of the mirror the whole of *a b*, Fig. 6, (the visible portion of the fundus,) is illuminated, the whole of its image *b′ a′*, and therefore the whole area of the pupil, will be bright; if the mirror be rotated downwards as before, the diffusion image, indicated by the dotted line (Fig. 6), shifts upwards, leaving the

Fig. 6.

portion of $a\ b$ nearest to b (s) in shade, therefore the portion of the image, $a'\ b'$, nearest to b', will be in shade, and this corresponds to the upper part of the the pupil.—*i.e.* the "shadow" has moved *downwards*, or in the *same* direction as the mirror.

The higher the degree of ametropia, the larger is the area of the fundus seen at the distance at which the mirror is held; but, as the image in each case occupies the same area—namely that of the pupil, the fundus is more highly magnified in the lower degrees, hence, with the same actual movement of the mirror, a greater movement of the "shadow" is seen.

It is evident that we have in this test a means of ascertaining the kind of ametropia, and estimating approximately its degree; whilst, by placing lenses in front of the eye, we can discover, with a very near approach to accuracy, the one required for its correction.

With the eye hypermetropic, place in clip A, a succession of convex lenses of increasing power, the shadow will become less and less defined, and finally will be seen to change its direction; if however the intervals between the lenses used are small, it is evident that one may be found with which there is no shadow moving in any one direction; this will usually be found not to correspond with Emmetropia, but with low Myopia.

Theoretically, directly the rays from the eye under observation, are rendered parallel (Emmetropia), no real or virtual image of the fundus is formed; but, since parallel rays form an image on the observer's retina, this is projected as an erect virtual image; as soon as they become slightly convergent (Myopia), they no longer form a clear retinal image, and there is less tendency to form a projected image; when they are sufficiently convergent to meet in front of the observer a real inverted image is seen.

In practice, the glass should be found which removes the shadow, and then a small amount must be deducted to give the actual glass required to correct the Hypermetropia. After a few trials it will be found that we can always estimate with the same amount of accuracy, that is to say, that the same observer will always have to deduct the same amount, but different observers will estimate differently, some taking off nothing at all, others 0·50, or 1·0 D; these differences depend on the fact that some stop as soon as there is no definite shadow, others go on until its direction is just reversed; they also vary according to the amount of accommodation used by the observer.

The great value of the Shadow-test is however in Astigmatism. In clip A of the Emmetropic Eye place the +5 *cyl.*, with its axis horizontal; the horizontal meridian remains emmetropic, but the vertical is rendered myopic. If the mirror be now rotated on its vertical axis, the emmetropic appearance is seen, but if rotated on its horizontal axis, a shadow, having a horizontal edge, is seen to move in the same direction as the mirror.

The appearances seen can be explained by the rules for refraction at an astigmatic surface (vide page 17). Taking the above case of Simple Myopic Astigmatism, the horizontal meridian being emmetropic.—Of the rays from any point of the fundus, those which pass through the horizontal meridian are parallel, those which pass through the vertical are convergent, and will meet at the focus of the vertical meridian; in this instance this will be at 200 mm. from the lens, (205 from the eye,) therefore according to the rule given at page 17, there will be formed at this point a horizontal linear image of the point on the fundus; the effect of this (acting on every point of the fundus) is that only those lines are seen clearly whose direction is at right angles to the vertical meridian. If the glass retina be used and the ground glass screen placed in clip C, this can be proved by the images formed on the latter.

If the mirror be now rotated on a slightly oblique axis, the direction of the edge of the shadow will still be horizontal; and, although the real movement of the retinal flame-image will now be oblique, yet it will still appear to move at right angles to the edge of the shadow. If the cylinder be rotated it will always be found that the shadow has its edge at right angles to the ametropic meridian, *i.e.* parallel with the axis of the cylinder. The reason that the shadow always appears to move at right angles to its edge, was, I believe, first pointed out by Dr. Charnley* in the following way—Take a card and hold it partly across any circular aperture so that its edge crosses the latter obliquely, now move the edge of the card across the aperture in any direction, and it will be seen that whatever is the real movement, it always appears to be at right angles to the edge of the card.

By altering the length of the eye all the varieties of Astigmatism can be produced, (see table page 18) and the test should be repeated with all of them.

In each case the edge of the "shadow" will indicate the direction of one of the principal meridians, while the direction of its apparent movement will indicate the kind of Ametropia in the other principal meridian.

In Simple Hypermetropic Astigmatism the focus of the Hypermetropic meridian is behind the eye, but the same rule holds good; a linear image of any point on the retina is formed at the focus of this meridian, and its direction is at right angles to the meridian; so that if the horizontal meridian is hypermetropic, the vertical edge of the shadow will be seen, and so on.

Many other experiments will, no doubt, occur to the reader. I have merely endeavoured in the preceding pages to sketch such as appeared to me to best illustrate the main points connected with errors of refraction, and the use of the ophthalmoscope in diagnosing them.

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* Oph. Hosp., Rep. Vol. xiii, p. 364.

APPENDIX.

On pages 13 and 15 it has been stated that the respective positions of the retina (f), and the "far-point" of the eye ($pr.$) can be found from the formula—

$$\frac{1}{F} = \frac{1}{f} \pm \frac{1}{pr.}$$

it must, however, be understood that distances which are on opposite sides of the lens, are not measured from the same point in the lens. Those in front of the eye are measured from the *anterior nodal point*, and those behind the lens are measured from the *posterior nodal point*; and the scales on the sliding bar and on the eye, are respectively measured from these points.

The dimensions of the lens are as follows:—

Radius of Anterior Surface	383· m.m.
,, Posterior ,, ...	22·5 m.m.
Thickness of Lens	1·0 m.m.

The table on the next page shows the length which must be given to the eye in order to represent various degrees of Ametropia, the latter being in each case expressed by the strength of the lens which, placed in clip A, corrects the Ametropia.

These values are found in the following manner:—

In order that any lens may correct an Ametropic eye, its focus must coincide with the "far-point" of the eye. So that for each lens the principal focus must be found; this, allowing for the distance (5 m.m.) between clip A and the eye, will also be the "far-point" ($pr.$) of the eye, if the latter is rendered Emmetropic by the lens. The position of the retina (f) can then be found from the formula already given.

Examples.—(1.) To find the length (f) which must be given to the eye, in order that it shall present a degree of Myopia which will be corrected by — 5 D., placed in clip A.

$$\frac{1}{f} = \frac{1}{F} - \frac{1}{pr.} \left(pr. = \frac{1000}{5} + 5 = 205 \right)$$

$$\text{Therefore} \quad \frac{1}{f} = \frac{1}{40} - \frac{1}{205}$$

$$\text{And} \quad f = 49{\cdot}7$$

(2). To find the length which must be given to the eye, in order that it shall present a degree of Hypermetropia which will be corrected by + 5 D in clip A.

$pr.$, being now on the same side of the lens as f, takes the minus sign; and 5 m.m. must be subtracted instead of added, as in the preceding example:—

The formula now becomes—

$$\frac{1}{f} = \frac{1}{F} + \frac{1}{pr.} \left(pr. = \frac{1000}{5} - 5 = 195 \right)$$

$$\text{Therefore} \quad \frac{1}{f} = \frac{1}{40} + \frac{1}{195}$$

$$\text{And} \quad f = 33{\cdot}19$$

TABLE SHOWING MODE OF REPRESENTING VARIOUS DEGREES OF AMETROPIA.

MYOPIA.		HYPERMETROPIA.	
Correcting Lens in A.	Length of Eye.	Correcting Lens in A.	Length of Eye.
— 1. D.	41 66	1. D.	38·45
— 2. D.	43·47	2. D.	37·0
— 3. D.	45 36	3. D.	35·65
— 4. D.	47·44	4. D.	34 38
— 5. D.	49 7	5. D.	33 19
— 6. D.	52·17	6. D.	32 06
— 7. D.	54 83	7. D.	31·0
— 8. D.	57·77	8. D.	30

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